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BIOELECTRIC CONTROL SYSTEMS

A. Kobrinskiy

Doctor of Technical Sciences

In 1958, the tenth issue of our journal was devoted almost entirely to problems of radio-electronic methods in medicine and biology. Since that time many interesting events have taken place, a number of original works have been carried out, and new electronic instruments for medicine and biology have been created. Consider the All-Union Conference on Medical Electronics, several international conferences, the attraction of engineers and physicists to research organizations occupied with solving biological problems, the training in a number of technical institutions of specialists in medicine and biology, the theoretical works of physicists and mathemeticians in the areas of higher nerve activity, bioenergetics, electrophysiology, the structure and functions of living cells, etc.

Although the work on the border line of the exact and natural sciences is still unfolding, even today a number of encouraging practical attainments can be noted in this area. The prosthesis of the arm with bioelectric control, created by a group of Soviet scientists and which received high recognition in our country as well as abroad, should be added to this number.

Besides the director of operations, a specialist in the theory of mechanisms and machines, A. Ye. Kobrinskiy, the following people took part in the development and investigation of systems of bioelectric control: Doctor of Medical Sciences B. P. Popov, Electrophysiologist and Candidate of Medical Sciences V. S. Gurfinkel', Candidate of Biological Sciences Ya. L. Slavutskiy, Candidates of Technical Sciences Ya. S. Yakobson and D. M. Ioffe, Candidate of Physicomathematical Sciences M. L. Tsetlin, Radio Engineers Ye. P. Polyan and A. Ya. Sysin, Structural Engineers M. G. Breydo and S. V. Bolkhovitin, and also Physician-Prosthetisist L. M. Voskoboynikova. The joint endeavor of so wide a circle of specialists working in

various areas of science and engineering are to a considerable extent responsible for the practical successes attained.

The working of prosthesis with bioelectric control is based upon the fact that a signal-command about some action, which is sent by a nerve fiber to a kinetic muscle, is accompanied by weak electrical signals. These signals may be recorded along the entire path from the brain to the muscle. They are biocurrents, drawn from kinetic muscles and used to control prosthetic mechanisms.

Without a doubt the positive results obtained in the area of bioelectric control will open many extraordinarily interesting perspectives.

Over 150 years ago, the famous Italial scientist Galvani established that living tissue reacts to electrical stimulation. Later it was discovered that most processes in living organisms are accompanied by electrical signals.

In the area of study of bioelectric phenomena, substantial results have been attained so far. More or less detailed studies have been made of the amplitude and frequency characteristics of the biocurrents of the brain (electroencephalography), the heart (electrocardiography) and the sensitive elements of the retina of the eye (electroretinography). Considerable attention has been and is being devoted to the study of biocurrents of the skeletal muscles (electromyography), which are used for bioelectric control.

All motion of a living organism is preceded by a change in the biocurrents in the corresponding muscles, which realize the motion. This is illustrated by Fig. 1, where the mechanogram 1 (graph of motion) of the bending of the wrist and the myogram 2 (graph of biocurrent) of the musculus flexor of the wrist are recorded simultaneously. The command to bend the wrist is sent by a light signal, the appearance of which was recorded at point a. The time interval from the moment of sending the command to the moment of biocurrent formation in the muscle and the time interval characterizing the delay of motion relative to the moment of biocurrent formation are clearly visible in the photograph.

Biophysicists and electrophysiologists have devoted a great deal of effort to

the study of bioelectric signals. Information is transmitted by these signals from the sense organs to the brain, and from the brain to other organs, for example, to kinetic muscles. One of the most important results of these studies was the discovery of the so-called "all or nothing" law. It was found that if stimulation applied to a nerve cell does not reach a definite threshold value, no signal is formed in the nerve fiber. A signal appears only if stimulation exceeds the threshold value. In this case discrete pulses are transmitted by the nerve fiber. The higher the frequency of the pulses the higher the level of stimulation. The amplitude of the pulses is not a function of the level of stimulation and always remains constant (on the order of 0.1 v). The rate of pulse propagation through the nervous system does not exceed 100 m/sec, while the frequency of pulses may reach 300 to 500 cps.

It is interesting to note that similar sets of discrete electric signals are used widely for programming the most varied modern automatic systems. Examples are: high-speed computers, systems of digital control of lathes, and a number of others. Of course, the analogy in the given case has a purely external nature. The nature of command pulses in a machine and in a living organism is completely different, as well as the methods of coding and transmitting these pulses to the executing organs.

The problem of using bioelectric signals to control engineering devices may in itself be divided into a number of simple problems: a) the development of effective methods of removing bioelectric signals from a living organism; b) the creation of methods and devices for amplifying and decoding these signals in order to separate useful information about commands reaching the points of biocurrent removal; c) the development of execution mechanisms which realize a given program of action; and d) the creation when necessary of special devices to provide feedback between the engineering device and the living organism.

The first mock-up of a bioelectric control system in the form of a artificial

human hand was made in 1957. It was controlled by muscle biocurrents, which flexed and extended the fingers. The biocurrents were picked up by electrodes installed in a special bracelet placed around the controlling muscles of the forearm.

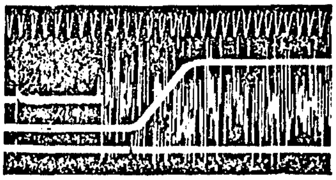

Fig. 1. Flexing of wrist:
1 - mechanogram of motion,
2 - myogram.

In this method of biocurrent pickup, the signal has a complex noise character (curve 2, Fig. 1). This is explained by the fact that the biocurrents represent the total effect of the action of a set of fibers of the given muscle, and also of numerous oscillations from the fibers of neighboring muscles, which create an additional noise background. Therefore, it is first of all necessary to process this complex signal so that useful information about commands may be separated from it. The commands go from the central nervous system to the muscle and control its voltage level.

So far only one signal parameter, its strength, has been used as a carrier of useful information in bioelectric control systems. Signal strength is within definite limits a linear function of the voltage level of the muscle. The biocurrents picked up are first amplified (see schematic in Fig. 3), after which the wave envelope is separated which characterizes the average signal strength. It is this parameter that was used for control. However, in the first mock-up, where a differential step-by-step switch was used as the electrical conductor, it was found necessary to introduce still another conversion. As a result, the control program was in the final analysis a set of discrete signals of constant amplitude, frequency modulated in accordance with the amplitude envelope (Fig. 4). This conversion was accomplished by a relaxation thyraton. The first mock-up was an analog of the programming method used in the so-called open-circuit step-by-step digital control systems.

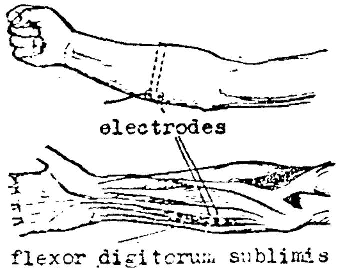

Fig. 2. Biocurrent pickup by electrodes.

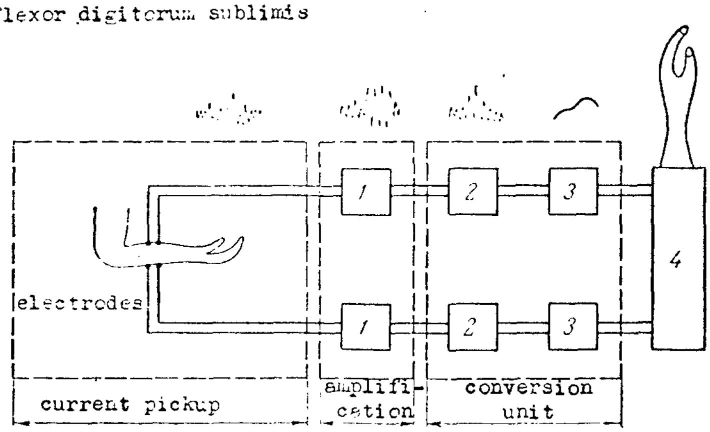

Fig. 3. Schematic diagram of bioelectric control system: 1 - amplifier; 2 - rectifier; 3 - scope; 4 - execution organ.

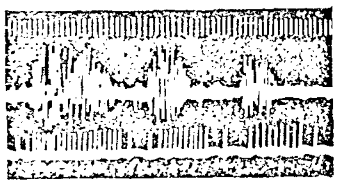

Fig. 4. Conversion of signal into a set of frequency-modulated pulses.

In constructing the first mock-up, the aim was to check the validity of the initial idea and to find out whether it is possible to use muscle biocurrents to control engineering devices. Naturally, problems of decreasing the weight and dimensions of the system, and problems of its reliability and life, gave rise to the second plan.

After the experiments on the first mock-up confirmed the validity of the initial assumptions, work was started on the second mock-up (Fig. 5), which was designed for the experimental study of operator trainability and the testing of the reliability and life of the individual components of the system, namely,

miniature semiconductor biocurrent amplifiers (Fig. 6). The execution mechanisms for operating the hand in this mock-up were electrohydraulic joints, which are used in the construction of machines having digital control.

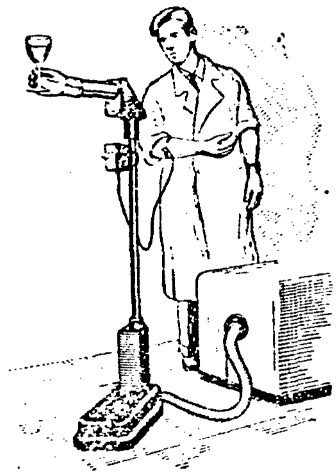

Fig. 5. Second mock-up of a bioelectric control system.

An experiment run in the process of developing and studying the first two mock-ups made it possible to move to the solution of an important practical problem—the prosthesis of the forearm with bioelectric control. The problem was the usual one in prosthesis, that of the partial restoration of functions lost as a result of amputation. However, distinguished from the existing method of prosthesis of the forearm, it was now possible to use external power sources for control, not muscular power. Control is accomplished by the bioelectric signals formed in excised muscles of the forearm. It is obvious that those general requirements which arise in the marking of any portable device were taken into account in the development of prosthesis; lightness, small dimensions, reliability and good outward appearance.

The execution organ was made in the form of a hand whose fingers closed in a pinching position. The operating mechanism of the hand was designed in such a way that in grasping and opening, the thumb and a unit of the four fingers moved

simultaneously. To control this hand it was necessary to use two independent signal sources; one for grasping and the other for opening. The operation was accomplished with a reversible motor with a special gear mechanism.

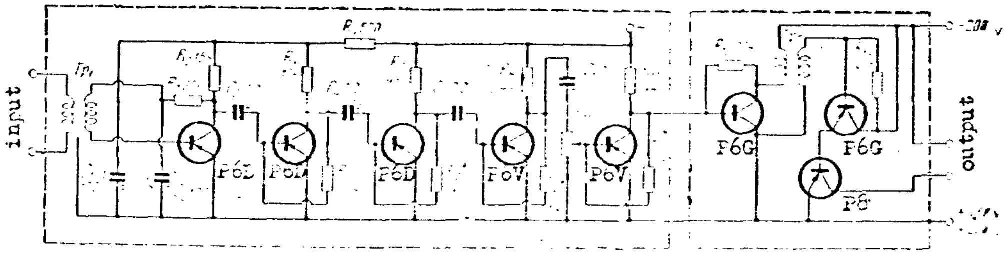

Fig. 6. Schematic diagram of the electronic control circuit.

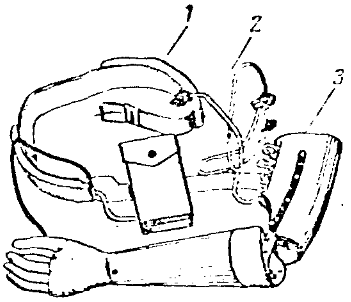

Fig. 7. Prosthetic forearm with bioelectric control: 1 - electrodes; 2 - electronic unit with current source; 3 - execution organ.

The signal sources were those groups of muscles of the stump to which prosthesis is to be applied, which in a healthy person accomplish the functions of flexing the wrist and fingers. Owing to this, the coordination habits which applied before amputation are used for control.

Figure 7 shows a drawing of the first prosthetic forearm with bioelectric control.

In the first mock-ups feedback was accomplished visually. The operator of the mock-up followed the position of the artificial hand directly and in accordance with his observations and natural intentions, applied the appropriate muscle.

Later, "sensing" methods were put forth, in particular the use of a vibrator (of the type used in a hearing-aid bone-conduction earpiece), to which signals proportional to the gripping of the hand are sent from the circuit of the motor.

However, the first experiments showed that prosthesis, even if not equipped

with special devices, was to a certain extent "sensitive," since the sources of the feedback signals were weak noises and vibrations, which accompanied the operation of the motor. The created the "sensing" of the working regime of the system and, in particular, the fource with which the artificial hand grasped an object.

The first experiments showed that the use of bioelectric systems introduces new possibilities in the application of prosthesis. The bioelectric prosthetic forearm in no way hinders the motion of the prosthetized limb. Control of the prosthetic appliance does not require considerable strength and is freely accomplished in any position of the arm.

Regarding the dynamic qualities of prosthesis with bioelectric control, they may be judged from the oscillogram in Fig. 8.

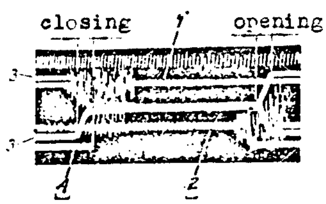

Fig. 8. Recording of motion cycle of prosthetic device: 1, 2 - myograms of musculus flexor and musculus extensor respectively; 3 - recording of "grasping" motion; 4 - recording of force exerted by the hand.

There is no doubt that the further development of works in the use of muscle biocurrents for control purposes in an important task. Because of this there is great interest in the question of whether it is possible to further miniaturize the circuits carrying information from a living organism to an external device. For example, will it be possible for the operator to use not the biocurrents from the muscles for control, but to use directly the biocurrents of the central nervous system, biocurrents from the brain?

A large branch of biophysics, electroencephalography, is occupied with the study of bioelectric processes in the human brain. In recent years, these processes have been studied intensely by physicists and mathematicians. Devices for picking up and processing bioelectric signals are continually being improved. Therefore, it will be no surprise if, in the not too distant future, technological

methods reach a level which will allow problems on the direct use of the brain's biocurrents for control to be solved.

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